Chapter 2

Simulation Modeling

2.1 Model Development

The Bill Williams River Corridor Technical Committee (BWRCTC) successfully developed and applied an HEC-5 model of the Bill Williams River system to test alternatives during their cooperative analysis. HEC-5 is a flexible and widely used data-driven reservoir model, but is not currently configured to accept operating rules expressed with boolean (i.e. IF - THEN) statements. Analysis of the HEC-PRM model results for Alamo Reservoir indicated that this type of rule form could be promising. Since the Bill Williams River system is relatively simple to model, (one reservoir and a few routed stream reaches), a customized simulation model was developed for the system to allow the use of any operating rule and also to facilitate probabilistic simulation used to study issues regarding eagle nesting, rather than modify HEC-5 to perform this study.

This custom simulation model, referred to as AlamoSim, was configured to represent the Bill Williams River system as shown in Figure 2.1. The model uses a computational approach based on the Euler solution technique for finite difference equations as follows:

Step 1. Estimate the change in storage over a small interval Δt.

Δstorage = Δt * flow

Calculate new value for storages based on this estimate.

$\text{Storage}_t = \text{Storage}_{t-\Delta t} + \Delta\text{storage}$

Step 2. Calculate new values for flows and other calculations in order of evaluation.

Other calculations = f(storages, flows, other calculations)

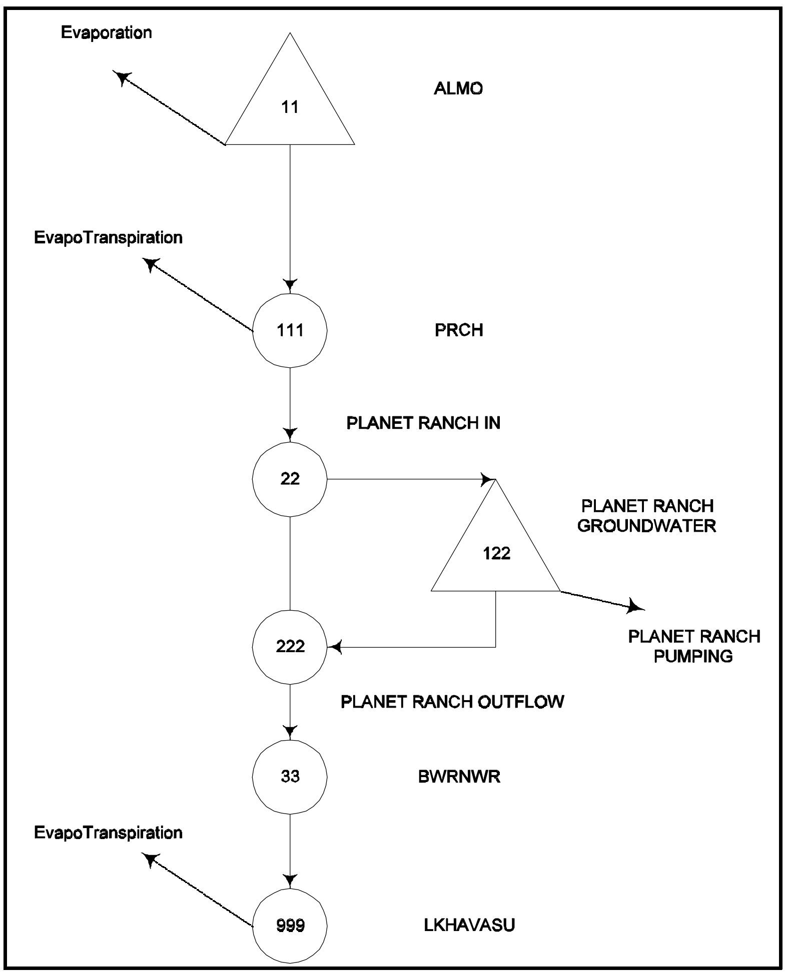

Figure 2.1 System Schematic as Modeled

Flows = f(storages, flows, other calculations)

Step 3. Update simulation time. Stop iteration when Time $\geq$ simulation stop time.
Time = Time + Δt

The AlamoSim model incorporates features used in the HEC-5 model of the Alamo system that are relevant to this study, including pumping from Planet Ranch, simplified stream and aquifer interactions, and Bill Williams River channel flows. The specifics are outlined in Appendix B.

2.2 Model Comparison

Both the HEC-5 model, (developed by the BWRCTC), and the AlamoSim model are daily simulation models used to evaluate operational alternatives for the Bill Williams River corridor. The models simulate operation of Alamo reservoir for different operating rules based on the historical record of daily inflows (almost 68 years). Performance for each alternative is measured by a set of evaluation criteria (or indicators) for each operating purpose (defined in Table 2.1). The evaluation criteria were identified by the subcommittees involved in the BWRCTC based on how reservoir operation (storage and releases) affects the different operational objectives. The purpose of the AlamoSim model is to evaluate operational strategies and compare their performance to those alternatives simulated with the HEC-5 model. To make meaningful comparisons, the AlamoSim model must be shown to produce results similar to the HEC-5 model given the same inputs. Before comparing model performance, some discussion of data analysis techniques is needed.

Table 2.1 BWRCTC Alternative Evaluation Criteria Definitions

Criteria	Description
Riparian Criteria	
RA1	Percent of time stream-flows at Refuge >= 18 cfs
RA2	Percent of time Alamo water surface elevation (WSE) between 1,100 and 1,171.3 feet
RA3	Percent of time Alamo Dam releases >= 25 cfs in November through January
RA4	Percent of time Alamo Dam releases >= 40 cfs in February through April and in October
RA5	Percent of time Alamo Dam releases >= 50 cfs in May through September
RA6	Total number of occurrences that Alamo Dam releases >= 1,000 cfs seven or more consecutive days in November through February
RA7	Total number of occurrences that Alamo Dam releases >= 1,000 cfs seven or more consecutive days in March through October

Criteria	Description
	Fisheries Criteria
F1	Percent of time WSE between 1,110 and 1,125 feet
F2	Percent of time in March 15 through May 31 WSE fluctuates more than 2 inches per day **
F3	Percent of time in March 15 through May 31 WSE fluctuates more than 0.5 inches per day **
F4	Maximum WSE drop in feet in June through September for the period of record **
F5	Average daily release during June through September
F6	Average daily release during October through May
F7	Percent of time stream-flows at Refuge >= 25 cfs
	Wildlife Criteria
W1	Percent of time WSE at or above 1,100 feet
W2	Number of times during the year that WSE > 1,135 feet two or more consecutive days
W3	Number of times from December 1 through June 30 that WSE > 1,135 feet two or more consecutive days
	Recreation Criteria
RE1	Percent of time WSE >= 1,090 feet
RE2	Percent of time WSE >= 1,094 feet
RE3	Percent of time WSE >= 1,108 feet
RE4	Percent of time WSE between 1,115 and 1,125 feet
RE5	Percent of time WSE between 1,144 and 1,154 feet
RE6	Percent of time outflow is between 300 and 7,000 cfs
RE7	Percent of time in March through May WSE between 1,115 and 1,125 feet
	Water Conservation Criteria
WC1	Average annual delivery of water in acre-feet to lower Colorado River (Lake Havasu)
WC2	Average annual Alamo Reservoir evaporation in acre-feet for period **
	Flood Control Criteria
FC1	Number of days WSE > 1,171.3 feet during period of record **
FC2	Maximum percent of flood control space used during period of record **
**	Note: Gray cells indicate that lower values are preferred

Data Analysis Techniques

Several data analysis techniques were used in this study to compare performance between operational alternatives. The BWRCTC compared alternatives simulated with HEC-5 using evaluation criteria identified by the technical subcommittees. Values for these criteria were computed by the Los Angeles District for each alternative using a post-processing program on a UNIX workstation. For this study, the Los Angeles District's post-processing program was modified to run on a personal computer and used to calculate evaluation criteria values for alternatives modeled with AlamoSim.

Since the BWRCTC evaluation criteria are based on discrete numbers, they potentially can convey misleading information. Extra care should be used with criteria based on a range of values such as RE4, RE7, and F1. For instance, when computing the value for RE4 (% of time WSE between 1,115 and 1,125 feet), water surface elevations very near 1,125 (e.g. 1,125.01) are not counted. Using discrete performance indicators alone can sometimes suggest misleading conclusions. When testing AlamoSim, values for RE4, RE7, and F1 for the AlamoSim Base Case were computed to be between 7% and 12% lower than for the HEC-5 Base Case. This apparent difference in performance is shown in Figure 2.2 (see RE4, RE7, and F1). These evaluation criteria differences resulted from slight numerical variations in water surface elevations that do not translate to real performance differences. When the three evaluation criteria are modified slightly to include an upper bound of 1,125.1 (instead of 1,125.0) the results are much closer between the AlamoSim and HEC-5 Base Case. The right side of Figure 2.2 shows values for the modified evaluation criteria labeled RE4.1, RE7.1, and F1.1.

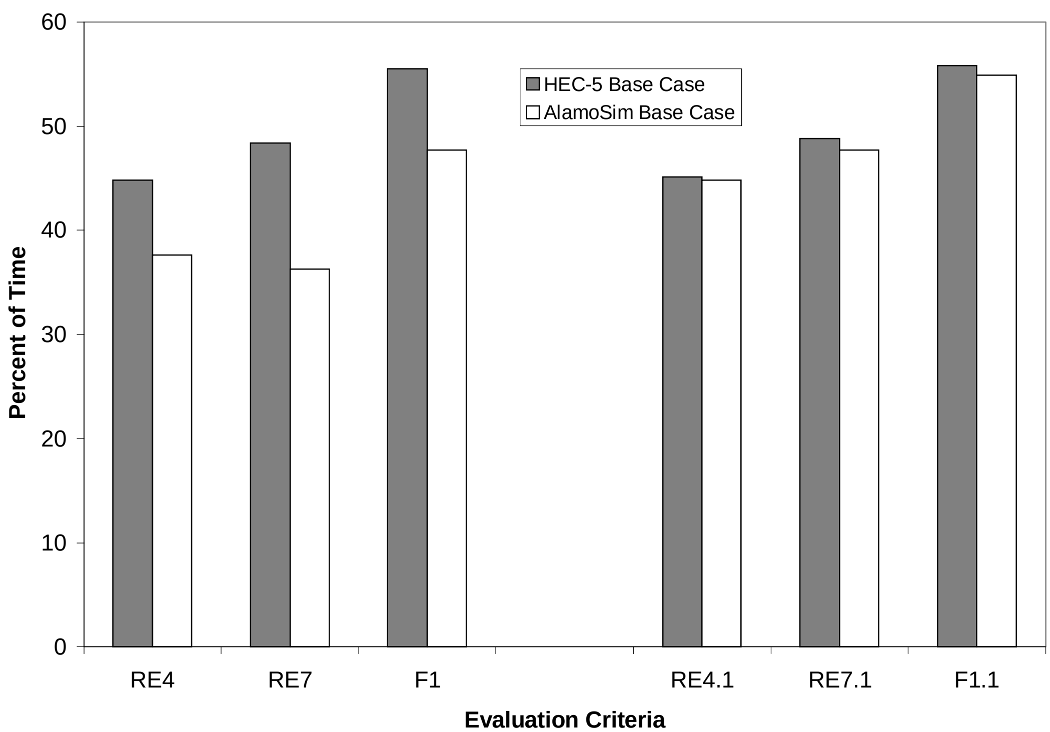

Figure 2.2 Differences in Evaluation Criteria Due to Discrete Performance Indicators

Hazards of discrete performance indicators can be offset by augmenting the indicators with continuous probability distributions. For this study, an additional post-processing program was written to compute exceedance probabilities for storage, elevation, and flow. Plots of the exceedance curves complement the evaluation criteria summary tables by offering a more complete picture of performance values.

Another useful data analysis tool is time series plots of storage, elevation, or release. These plots are important to show operational differences between alternatives that can not be conveyed through discrete or probabilistic performance indicators.

Validating AlamoSim

To demonstrate that AlamoSim can be used to test new alternatives and make direct comparisons with the HEC-5 results, a simple alternative tested in the BWRCTC was selected to simulate with AlamoSim. The alternative chosen for comparison was A1125WOD. This alternative represents the BWRCTC's recommended operating plan with no maintenance draw-downs. This alternative allowed direct comparison of the basic operating plan and the stream-flow routing routines without having to duplicate the draw-down plan tested in HEC-5. If the results from the two models simulating the same conditions are the suitably close, then it is assumed that AlamoSim can be used to test new alternatives. The AlamoSim results can be directly compared to previous results from the HEC-5 model.

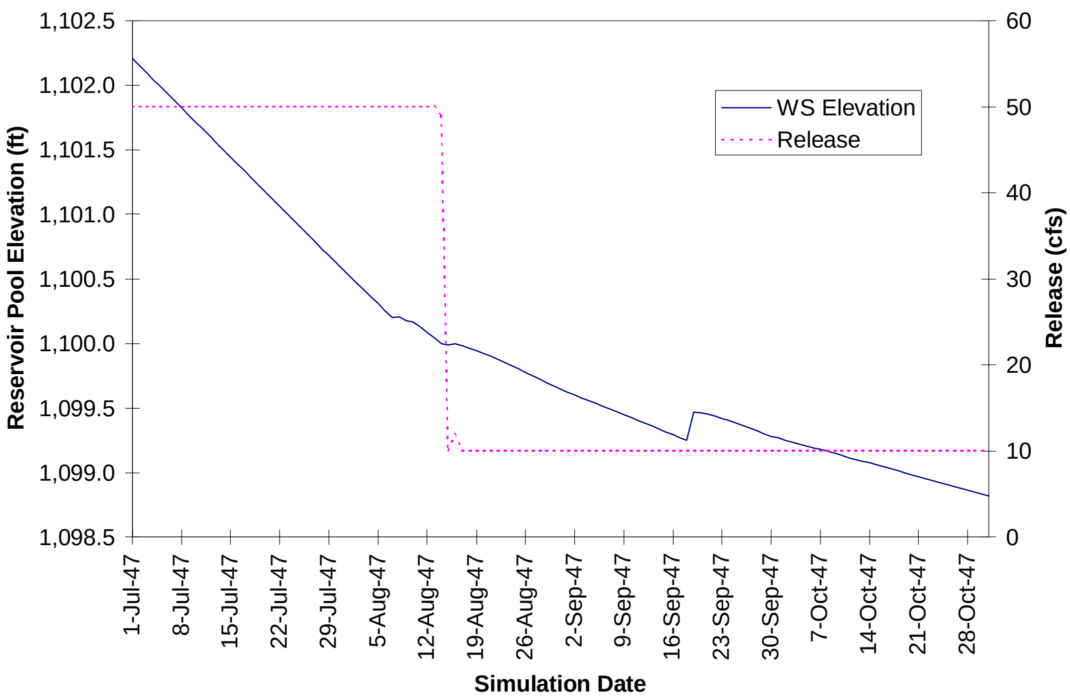

Figure 2.3 Release Compared to Elevation for HEC-5 Base Case

While comparing the two models, an apparent discrepancy was found between the operation rule input into HEC-5 and the model output. According to the recommended operating plan presented in the *Proposed Water Management Plan* (BWRCTC 1994), when the Alamo water surface elevation is between 1,070 and 1,100 feet, releases should be 10, 15, or 25 cfs depending on the date. When the lake elevation drops below 1,070 feet, the release should be 10 cfs. The elevation and release results from the HEC-5 Base Case (A1125WOD) indicate that the model is not working in this manner. Results indicate that HEC-5 releases 10 cfs at all times when the reservoir water surface is below 1,100 feet, regardless of the date. Figure 2.3 shows that when the water surface elevation drops below 1,100 feet, the release drops from 50 cfs to 10 cfs in August. According to the recommended operating plan, the release should be 25 cfs in August and 15 cfs starting October 1. The AlamoSim Base Case operating plan was modified to reflect actual results of the HEC-5 model. (This is not a new plan, merely a correction to reflect actual results from the Alamo model in HEC-5.) Table 2.2 shows the corrected operating rule used in the AlamoSim Base Case to compare with the HEC-5 Base Case.

Table 2.2 Revised BWRCTC Recommended Operating Plan

Reservoir Pool Elevation (ft)	Release (cfs)
1265	(Top of Dam)
1,235	(Top of flood control pool; Spillway Crest)
1,148.4	7,000
1,132	6,621 - 7,000
1,131	6,000
1,130	5,000
1,129	4,000
1,128	3,000
1,127	2,000
1,126	1,000
1,125	Transition up to 1,000

Releases for Lower Reservoir Pool Elevation By Season

Elev	Oct 1 - Oct 31	Nov 1 - Jan 31	Feb 1 - Mar 31	May 1 - Sep 30
1,100	40 cfs	25 cfs	40 cfs	50 cfs
1,070	10 cfs*	10 cfs	10 cfs**	10 cfs**
990	10 cfs	10 cfs	10 cfs	10 cfs

* Recommended Operating Plan specifies 15 cfs
** Recommended Operating Plan specifies 25 cfs

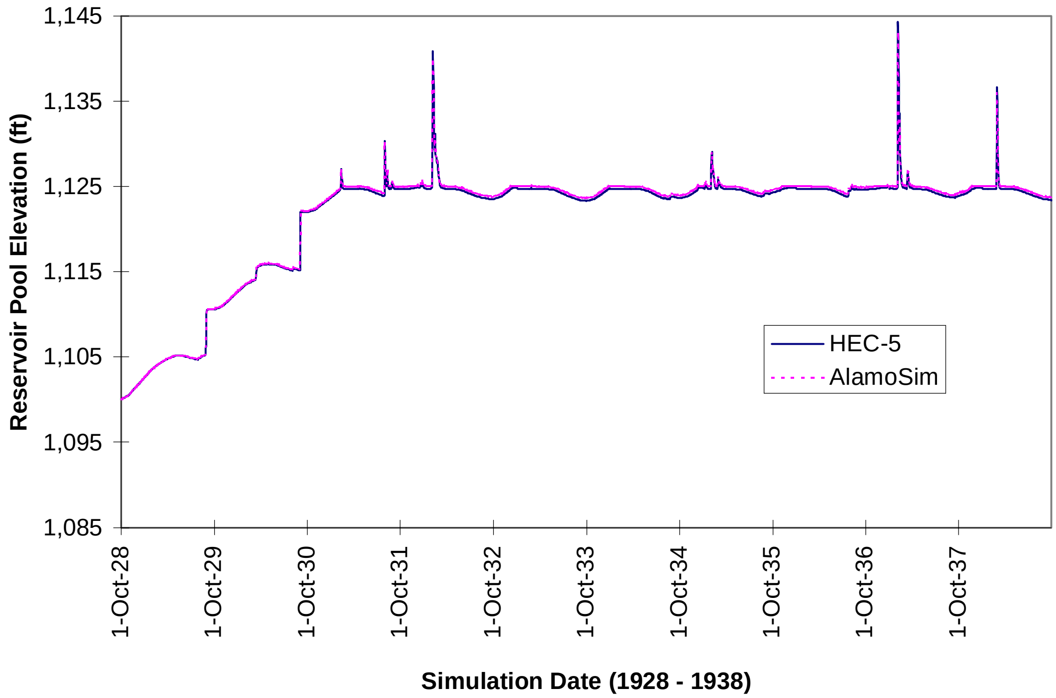

Figure 2.4 Elevation Time Series for HEC-5 and AlamoSim Base Case (1928-38)

Figure 2.4 shows the first ten years of reservoir pool elevation results for the HEC-5 (A1125WOD) and AlamoSim Base Case. The elevation results are very similar, with AlamoSim operating at a slightly higher elevation in some cases. The difference is usually within two to three inches, and does not increase over the simulation period. Figure 2.5 is a plot of the Alamo reservoir water surface elevation exceedance probabilities for the two models. The curves are almost identical traces. The horizontal axis represents the percent of days during the simulation period that an elevation (represented on the vertical axis) is exceeded. For instance, according to Figure 2.5 the water surface elevation is at or above 1,115 feet approximately 49% of the days for both alternatives and at or above 1,125 feet approximately 5% of the days. From these two percentages we can estimate the percent of days the elevation is between 1,115 and 1,125 feet (Evaluation Criteria RE4) to be 44%. (Compare this value to that for RE4 and RE4.1 in Table 2.3.) The water surface elevation time series plots and exceedance curves demonstrate that the AlamoSim and HEC-5 models produce nearly identical results when simulating the same operating rules and input data.

Finally, the evaluation criteria from the Los Angeles District's post processor were used to compare the models. Table 2.3 contains a summary of the evaluation criteria values for the HEC-5 Base Case (A1125WOD) and the AlamoSim Base Case. The evaluation criteria results are very similar except for RE4, RE7, and F1. RE4 values for the two models suggests that

AlamoSim keeps the water surface elevation of Alamo reservoir between 1,115 and 1,125 feet 7.2 % less than HEC-5. (See Figure 2.2.) However, the time series and exceedance probabilities shown above do not support this difference. This variance in the evaluation criteria values illustrates the potential hazard of using discrete performance indicators alone as mentioned above. AlamoSim results near 1,125 were often just over 1,125 (e.g. 1,125.02 ft) and HEC-5 results near 1,125 were often just below 1,125 (e.g. 1,124.95 ft). These slight differences in elevation do not represent significant differences in actual reservoir operation, but they cause the evaluation criteria values to suggest apparent differences. New evaluation criteria for RE4, RE7, and F1 were computed using an upper range of 1125.1 ft to account for the slight differences between how the two models operate near the 1,125 ft. water surface elevation. With the new evaluation criteria, (designated RE4.1, RE7.1, and F1.1), all of the evaluation criteria except RA7 match within 1.9 percent.

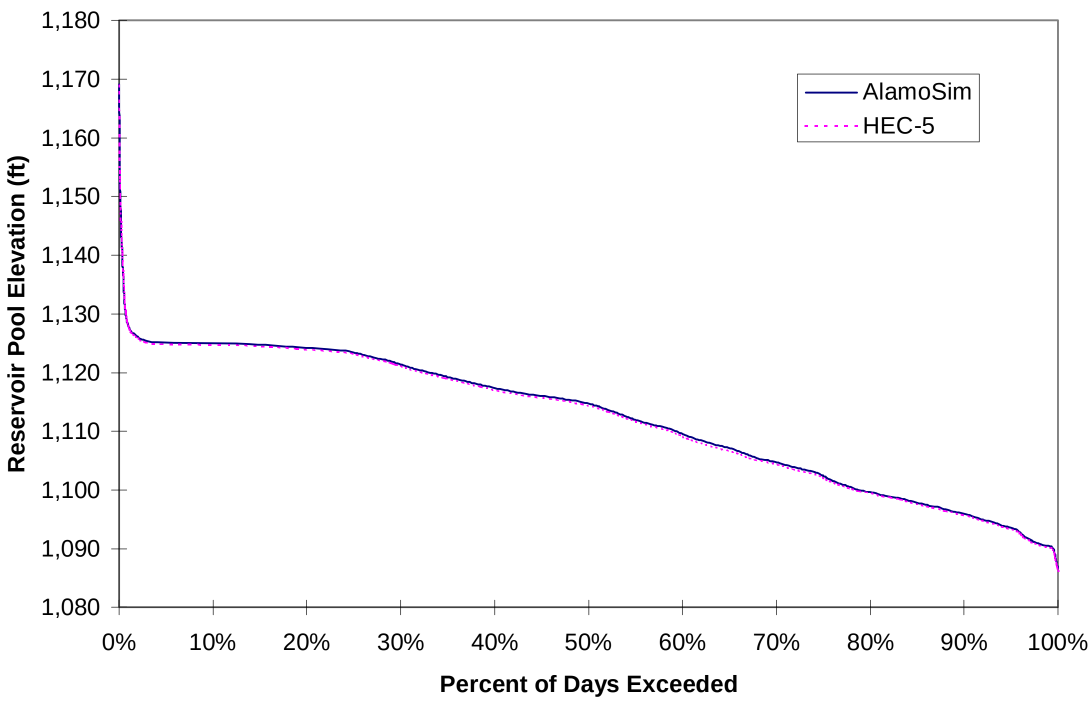

Figure 2.5 Elevation Exceedance Probabilities for HEC-5 and AlamoSim Base Case

The time series plots, elevation exceedance curves, and evaluation criteria for the two different models demonstrate that the AlamoSim model simulates the operation of Alamo Reservoir very similarly to the HEC-5 model for the same operating rules. Based on this comparison, variations of the operation of Alamo reservoir will be tested using AlamoSim and direct comparisons made to HEC-5 simulation results.

2.3 Updated Hydrologic Record

The Los Angeles District supplied a revised hydrologic record of daily inflows to Alamo reservoir. The new record includes corrections to the previous record and extends the record from 31 December 1993 to 29 August 1996. Five missing values were found in the updated record. These missing values were edited as shown in Appendix C. The revised record is used as the standard period of record for all of the new alternatives evaluated. Since the new record will impact simulation results, the rule used in the AlamoSim Base Case alternative was simulated with the new hydrologic record to quantify the differences between the revised record and the previous record. This new base condition is called the "Updated Base Case".

The elevation results for the Updated Base Case and Base Case are the same until the spring of 1970. Figure 2.6 is a plot of reservoir water surface elevation for the two alternatives from 1928 to 1996. The revised hydrology causes a slightly higher water surface elevation for much of the simulation period between February 1970 and December 1993. Elevation exceedance probabilities are plotted in Figure 2.7 confirming that the Updated Base Case maintains slightly higher elevations more frequently when water surface elevation is below 1,120 feet.

Table 2.3 Evaluation Criteria Values for HEC-5 and AlamoSim Base Case

	HEC-5	AlamoSim		HEC-5	AlamoSim
Criteria			**Criteria**		
Min WSE (ft)	1,086.2	1,086.5	W2 (#)	13	13
Mean WSE (ft)	1,111.9	1,112.2	W3 (#)	12	12
Max WSE (ft)	1,170.0	1,169.1	F1 (%)	55.5	47.7
RE1 (%)	99.3	99.5	F1.1 (%)	55.8	54.9
RE2 (%)	93.6	94.0	F2 (%)	4.6	4.5
RE3 (%)	61.8	62.9	F3 (%)	30.6	30.2
RE4 (%)	44.8	37.6	F4 (ft)	9.0	8.4
RE4.1 (%)	45.1	44.8	F5 (cfs)	55	56
RE5 (%)	0.2	0.2	F6 (cfs)	142	142
RE6 (%)	3.2	3.3	F7 (%)	14.4	15.5
RE7 (%)	48.4	36.3	RA1 (%)	49.5	47.6
RE7.1 (%)	48.8	47.7	RA2 (%)	78.2	78.7
WC1 (af)	51,490	51,709	RA3 (%)	75.6	75.9
WC2 (af)	16,804	16,652	RA4 (%)	79.8	80.2
FC1 (#)	0	0	RA5 (%)	78.3	79
FC2 (%)	0.0	0.0	RA6 (#)	15	15
W1 (%)	78.2	78.7	RA7 (#)	16	15

RE1 - % of time WSE at or above 1090'
RE2 - % of time WSE at or above 1094'
RE3 - % of time WSE at or above 1108'
RE4 - % of time WSE between 1115' and 1125'
RE4.1 - % of time WSE between 1115' and 1125.1'
RE5 - % of time WSE between 1144' and 1154'
RE6 - % of time Outflow between 300 and 7,000 cfs
RE7 - % of time in March thru May WSE between 1115' and 1125'
RE7.1 - % of time in March thru May WSE between 1115' and 1125.1'
WC1 - Avg annual delivery of water to Lake Havasu
WC2 - Avg. annual evaporation in ac-ft for simulation period
FC1 - No. of days WSE above 1171.3' during simulation period
FC2 - Max percent of flood control space used during simulation period
W1- % of time WSE at or above 1100'
W2- No. of times during the year that WSE exceeds 1135' two or more consecutive days
W3 - No. of times from 1 Dec thru 30 Jun that WSE exceeds 1135' two or more consecutive days

F1 - % of time WSE between 1110' and 1125'
F1.1 - % of time WSE between 1110' and 1125.1'
F2 - % of time in Mar thru May WSE fluctuates more than 2" per day
F3 - % of time in 15 Mar thru May WSE fluctuates more than 0.5" per day
F4 - Max WSE drop, in feet, in Jun thru Sep for simulation period
F5 - Avg. Daily release during Jun thru Sep
F6 - Avg. Daily release during Oct thru May
F7 - % of time stream flows at BW Refuge equal or exceed 25 cfs
RA1 - % of time stream flows at BW Refuge equal or exceed 18 cfs
RA2 - % of time WSE between 1100' and 1171.3'
RA3 - % of time Alamo releases >= 25 cfs in Nov thru Jan
RA4 - % of time Alamo releases >= 40 cfs in Feb thru Apr and Oct
RA5 - % of time Alamo releases >= 50 cfs in May thru Sep
RA6 - Total no. of occurrences that Alamo releases >= 1,000 cfs seven or more consecutive days in Nov thru Feb
RA7 - Total no. of occurrences that Alamo releases >= 1,000 cfs seven or more consecutive days in Mar thru Oct

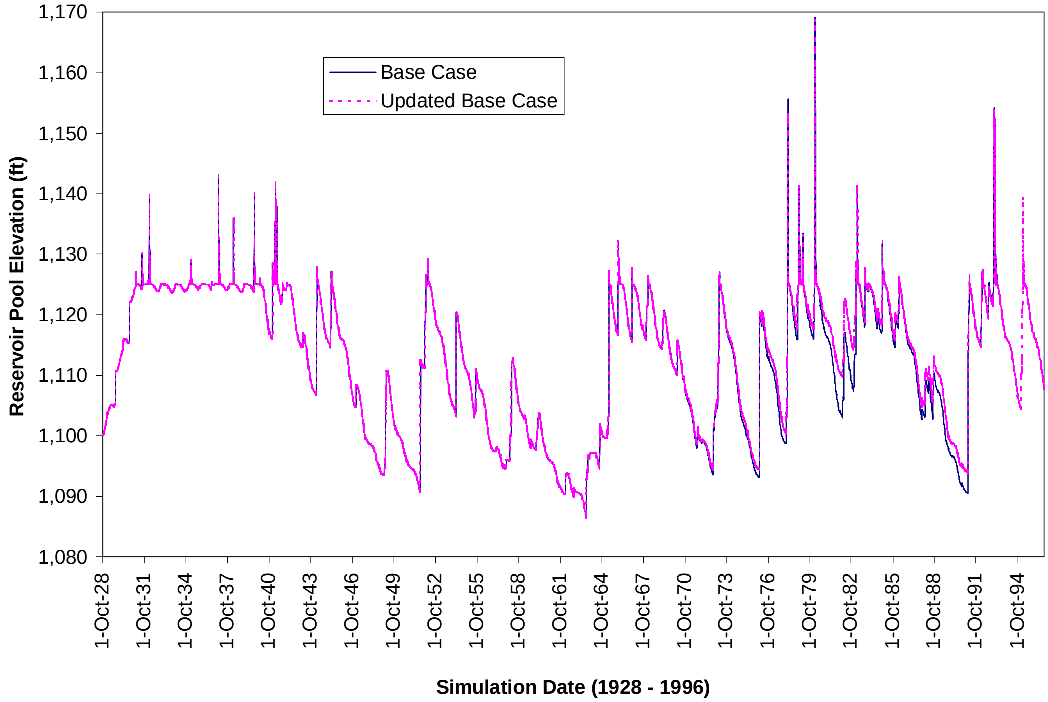

Figure 2.6 Elevation Time Series: Base Case vs Updated Base Case (1928 - 1996)

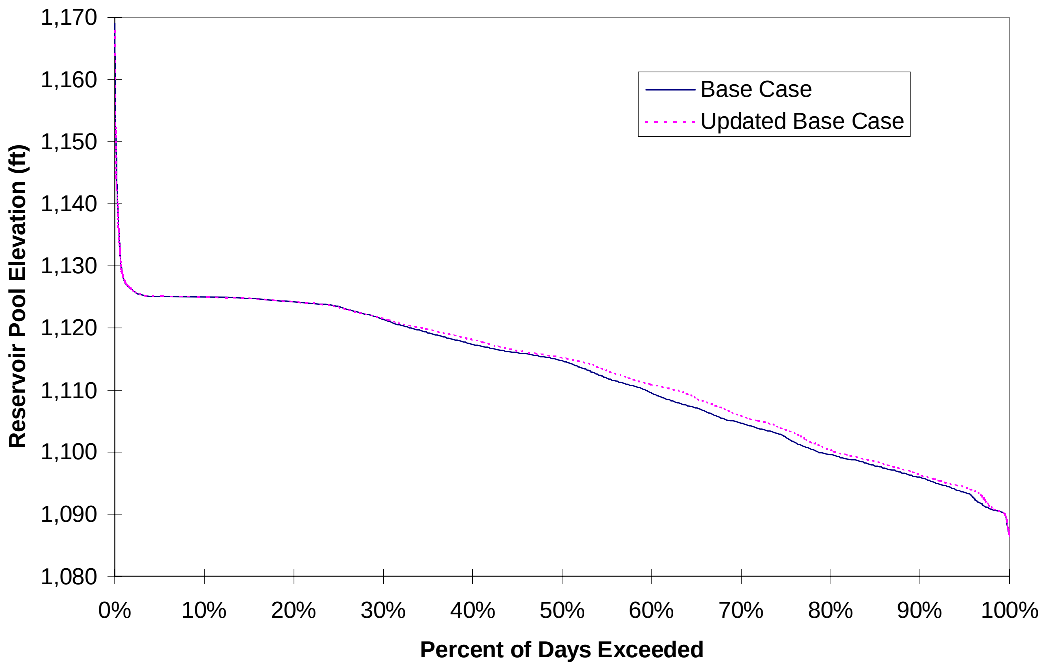

Figure 2.7 Elevation Exceedance Probabilities: Base Case vs Updated Base Case

Table 2.4 presents the evaluation criteria values for the Base Case and Updated Base Case. Figure 2.8 presents the summary data from Table 2.4 in graphical form. The alternative with the updated hydrology (Updated Base Case) does as well or better than the Base Case for all criteria except for W2, W3, and WC2. The Updated Base Case has slightly more evaporation because the reservoir storage is slightly higher over time than in the Base Case. These differences in operation are due solely to the updated hydrology. The operating rules were not changed between these alternatives.

Table 2.4 Evaluation Criteria Values for Base Case vs Updated Base Case

	Base Case	Updated Base		Base Case	Updated Base
Criteria			**Criteria**		
Min WSE (ft)	1,086.5	1,086.5	W2 (#)	13	14
Mean WSE (ft)	1,112.2	1,112.8	W3 (#)	12	13
Max WSE (ft)	1,169.1	1,168.7	F1 (%)	47.7	51.3
RE1 (%)	99.5	99.5	F1.1 (%)	54.9	58.3
RE2 (%)	94.0	95.7	F2 (%)	4.5	4.3
RE3 (%)	62.9	66.2	F3 (%)	30.2	26.6
RE4 (%)	37.6	39.3	F4 (ft)	8.4	8.1
RE4.1 (%)	44.8	46.4	F5 (cfs)	56	56
RE5 (%)	0.2	0.2	F6 (cfs)	142	143
RE6 (%)	3.3	3.3	F7 (%)	15.5	15.6
RE7 (%)	36.3	37.0	RA1 (%)	47.6	50.7
RE7.1 (%)	47.7	48.3	RA2 (%)	78.7	80.5
WC1 (af)	51,709	52,689	RA3 (%)	75.9	78.0
WC2 (af)	16,652	16,997	RA4 (%)	80.2	81.8
FC1 (#)	0	0	RA5 (%)	79	80.9
FC2 (%)	0.0	0.0	RA6 (%)	15	16
W1 (%)	78.7	80.5	RA7 (%)	15	16

RE1 - % of time WSE at or above 1090'
RE2 - % of time WSE at or above 1094'
RE3 - % of time WSE at or above 1108'
RE4 - % of time WSE between 1115' and 1125'
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RE6 - % of time Outflow between 300 and 7,000 cfs
RE7 - % of time in March thru May WSE between 1115' and 1125'
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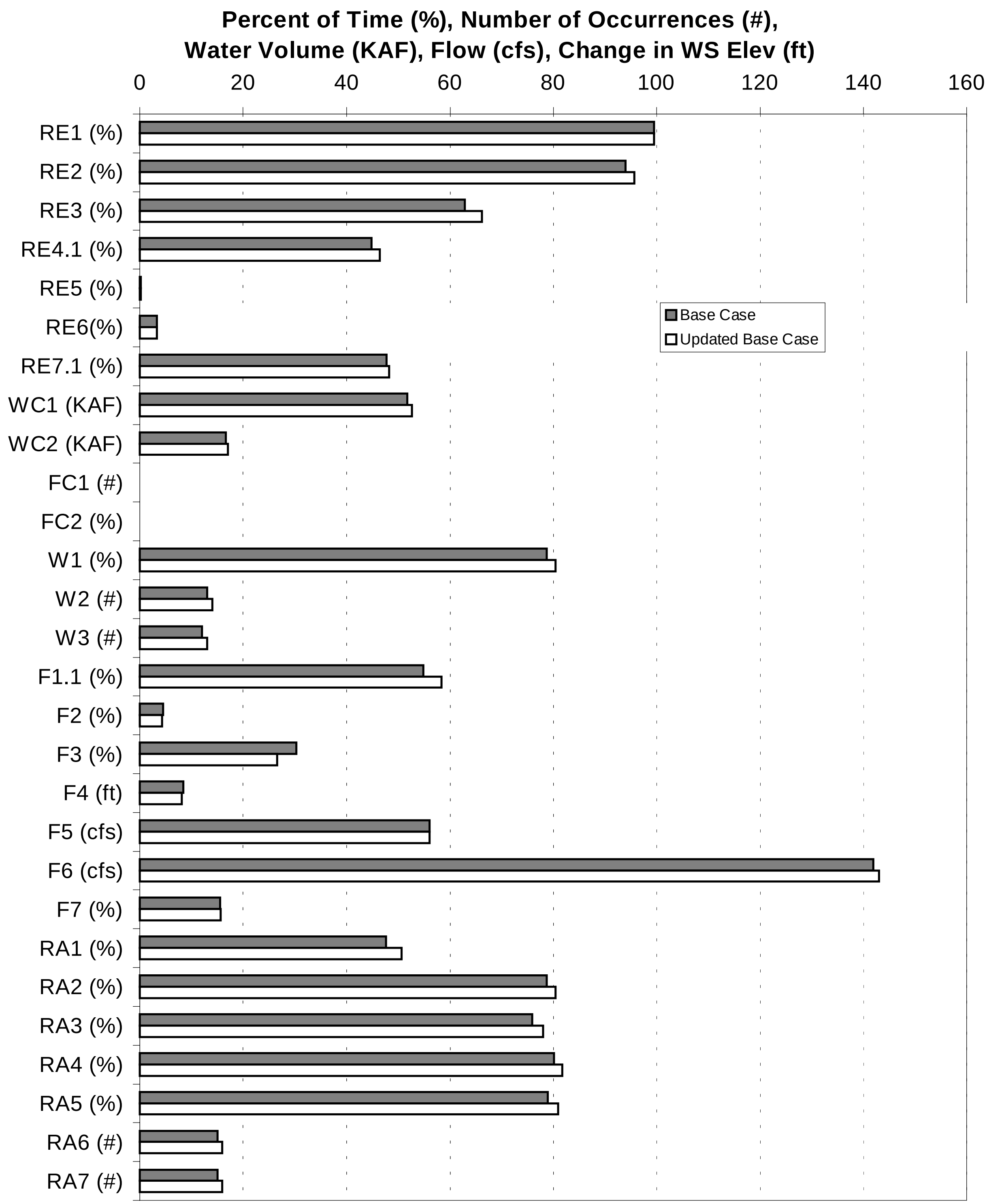

Figure 2.8 Evaluation Criteria: Base Case vs Updated Base Case